

09/22/81 Eastern Airlines

Official Accident Report Index Page

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Report Title Eastern Airlines Flight 935, Lockheed L-1011-385, N309EA, Near Colts Neck, New Jersey, September 22, 1981.

Report Date June 1, 1982

Organization Name National Transportation Safety Board Bureau of Accident Investigation Washington, D.C. 20594

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Keywords Rolls-Royce RB-211 engine; inadequate lubricating oil supply; low pressure location bearing; oil leaks; coupling seal displacement; oil spray; fire; fan shaft overheat; fan shaft failure; fail-safe shaft failure.

Abstract About 1140 e.d.t. on September 22, 1981, the No. 2 engine, a Rolls-Royce RB-211-22B, failed as Eastern Airlines Flight 935, a Lockheed L-1011-385 (N309EA), was climbing through 10,000 feet after departing Newark International Airport, Newark, New Jersey, for San Juan, Puerto Rico. The displacement of the fan module in the course of the engine failure sequence caused loss of hydraulic systems A, B, and D and jammed the captain's and first officer's rudder pedals in the neutral position. The flightcrew performed the appropriate emergency procedures, requested an immediate landing at John F. Kennedy International Airport, Jamaica, New York, and dumped about 48,000 pounds of fuel. The aircraft, with 11 crewmembers and 190 passengers aboard, landed on runway 22L at 2212 e.d.t. without further incident. No one aboard was injured, and there was no damage to property or injury to persons on the ground. The aircraft was substantially damaged. The National Transportation Safety Board determines that the probable cause of the accident was thermally induced degradation and consequent failure of the No. 2 engine low pressure location bearing because of inadequate lubrication. Oil leaks between the abutment faces of the

intermediate pressure compressor rear stubshaft and the low pressure location bearing oil weir and between the intermediate pressure location bearing inner front flange and the intermediate pressure compressor rear stubshaft reduced the lubricating oil flow to the low pressure location bearing which increased operational temperatures, reduced bearing assembly clearance, and allowed heat to build up in the bearing's balls and cage. The bearing failure allowed lubricating oil to spray forward into the low pressure fan shaft area where it ignited into a steady fire; the fire overheated the fan shaft and the fan fail-safe shaft both of which failed, allowing the fan module to move forward and break through the No. 2 engine duct. This caused extensive damage to the aircraft's structure and flight control systems. The oil leaks were most likely caused by poor mating of the abutment surfaces.

Facts of the Accident

Accident NTSB ID	82-05
Airline	Eastern Airlines
Model aircraft	L-1011-384, also referred to as L-1011-385-1, N309EA Serial No. 193A-1010
Year shipped	1972
Aircraft manufacturer	Lockheed
Engine type	RB211-22B
Engine manufacturer	Rolls Royce
Date	09/22/81
Time	1140
Location	Colts Neck, NJ
Country	USA
Fire during flight?	Y engine
Fire on the ground?	N
Probable cause	Thermally induced degradation and consequent failure of the No. 2 engine low pressure location bearing because of inadequate lubrication.
Contributing causes	Oil leaks between the abutment faces of the intermediate pressure compressor rear stubshaft reduced the lubricating oil flow to the low pressure location bearing which increased operational temperatures, reduced bearing assembly clearance, and allowed heat to build up in the bearing's balls and cage. The bearing failure allowed lubricating oil to spray forward into the low pressure fan shaft area where it ignited into a steady fire; the fire overheated the fan shaft and the fan fail-safe shaft both of which failed, allowing the fan module to move forward and break through the No. 2 engine duct. This caused extensive damage to the aircraft's structure and flight control systems. The oil leaks were most likely caused by poor mating of the abutment surfaces.
Weather conditions	Scattered clouds, visibility 5 miles
Total crew size	11
Cockpit crew size	3
Cabin crew size	8
Passengers	190
Report ID	NTSB-AAR-82-5
Pages	35
Day or night?	Day
Flight number	935

Flight origin	Newark, NJ
Flight destination	San Juan, Puerto Rico
Description	<p>The No. 2 engine failed as the aircraft climbed through 10,000 feet after takeoff. The displacement of the fan module in the course of the engine failure sequence caused loss of hydraulic systems A, B, and D and jammed the captain's and first officer's rudder pedals in the neutral position. Appropriate emergency procedures and fuel dumping were performed; the aircraft landed without further incident.</p>

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Synopsis

About 1140 eastern daylight savings time on September 22, 1981, the No. 2 engine, a Rolls-Royce RB-211-22B, failed as Eastern Airlines Flight 935, a Lockheed L-1011-385 (N309 EA), was climbing through 10,000 feet after departing Newark International Airport, Newark, New Jersey, for San Juan, Puerto Rico. The displacement of the fan module in the course of the engine failure sequence caused loss of hydraulic systems A, B, and D and jammed the captain's and first officer's rudder pedals in the neutral position. The flightcrew performed the appropriate emergency procedures, requested an immediate landing at John F. Kennedy International Airport, Jamaica, New York, and dumped about 48,000 pounds of fuel. The aircraft, with 11 crewmembers and 190 passengers aboard, landed on runway 22L at 1212 e.d.t. without further incident. No one aboard was injured, and there was no damage to property or injury to persons on the ground. The aircraft was substantially damaged.

The National Transportation Safety Board determines that the probable cause of the accident was thermally induced degradation and consequent failure of the No. 2 engine low pressure location bearing because of inadequate lubrication. Oil leaks between the abutment faces of the intermediate pressure compressor rear stubshaft and the low pressure location bearing oil weir and between the intermediate pressure location bearing inner front flange and the intermediate pressure compressor rear stubshaft reduced the lubricating oil flow to the low pressure location bearing which increased operational temperatures, reduced bearing assembly clearance, and allowed heat to build up in the bearing's balls and cage. The bearing failure allowed lubricating oil to spray forward into the low pressure fan shaft area where it ignited into a steady fire; the fire overheated the fan shaft and the fan fail-safe shaft both of which failed, allowing the fan module to move forward and break through the No. 2 engine duct. This caused extensive damage to the aircraft's structure and flight control systems. The oil leaks were most likely caused by poor mating of the abutment surfaces.

1. Factual Information

1.1 History of the Flight

On September 22, 1981, Eastern Airlines Flight 935 was being operated as an international scheduled passenger flight from Boston, Massachusetts, to San Juan, Puerto Rico, with an en route stop at Newark, New Jersey. According to the captain, the Boston to Newark flight was normal. Flight 935 taxied from the Eastern Airlines ramp at 1057,¹ received an instrument flight rules (IFR) air traffic control clearance, and was directed to runway 22L at Newark International Airport for takeoff.

The aircraft departed the airport at 1125, using a reduced thrust takeoff power setting of 1.522 engine pressure ratio (EPR). The takeoff and initial climb were normal. According to the flightcrew, as the aircraft was climbing through 800 feet,² they noted that the yellow warning light for the No. 2 engine fan airborne vibration monitor (AVM) had illuminated momentarily, indicating an abnormal level of vibration, then went out and did not come back on. Using the broad band vibrator filter selector, the flight engineer determined that while the No. 2 engine N_1 and N_3 rotor readings were normal, the N_2 rotor reading was high and off scale. The flightcrew stated that when power was reduced at 1,000 feet in accordance with the normal procedures all AVM readings were normal. Shortly thereafter, the No. 2 engine oil filter pressure warning light, which measures pressure differential across the filter, illuminated indicating that the filter could be blocked and that the filter may be operating in the bypass mode. The flightcrew then slowly retarded the No. 2 engine throttle to near idle. Oil pressure was steady at 50 psi, and the oil quantity was 15 quarts. Both readings are within normal limits. The captain directed the second officer to check the abnormal procedures section of the Flight Manual for corrective action to be taken when the oil pressure filter warning light illuminated.

All engine parameters, including AVM readings, were normal when the aircraft was leveled at 2,000 feet in accordance with departure instructions. In accordance with Flight Manual procedures, the flightcrew slowly reestablished climb power while monitoring all engine instruments. According to the flightcrew, as the aircraft climbed through 10,000 feet, they heard and felt a loud explosion accompanied by heavy aircraft buffeting. They stated that there was no advance warning and that immediately after the explosion numerous warning and caution lights illuminated.

The second officer called out that the No. 2 engine had failed and that hydraulic systems A, B, and D had been lost simultaneously. There were no concurrent pressurization problems. The No. 2 engine was shut down immediately, and the crew performed the engine shutdown and multiple hydraulic-system-failure checklists. Since the No. 2 engine fire warning systems would not test properly, the flightcrew discharged the fire bottle as a precautionary measure.

The flightcrew requested air traffic control clearance for an immediate descent and landing at John F. Kennedy International Airport, Jamaica, New York. The request was granted and the flightcrew was given headings to jettison fuel at 10,000 feet to reduce aircraft gross weight from 393,000 lbs. to 345,000 lbs. Airspeed was reduced from 320 to about 270 knots indicated airspeed (KIAS) to reduce buffeting. The captain and first officer noted that their rudder pedals were jammed in a neutral position.

The flightcrew made an approach to John F. Kennedy International Airport using elevators, ailerons, and differential power for aircraft control. The aircraft was landed on runway 22L at 1212. Crash/fire/rescue (CFR) units were standing by and after the aircraft stopped on the runway they inspected the exterior of the aircraft for damage and leaks and determined that there was no immediate danger. The captain taxied the aircraft to a parking gate and the passengers and flightcrew deplaned normally; no one was injured.

The accident occurred about 1140 during daylight hours at latitude 40°11'N and longitude 74°10' W.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others	Total
Fatal	0	0	0	0
Serious	0	0	0	0
Minor/none	<u>11</u>	<u>190</u>	<u>0</u>	<u>201</u>
Total	11	190	0	201

1.3 Damage to Aircraft

Inspection of the aircraft revealed that the No. 2 engine fan shaft had failed and that the fan assembly had moved forward about 12 feet in the No. 2 engine inlet "S" duct before breaking through both sides of the duct. (See figure 1.)

An inspection of the aircraft showed that a section of the No. 2 engine low pressure compressor rotor (fan) module, including the disc, the blades, and an attached 26-inch-section of the fan shaft, was missing from the engine. A coincidental 30-inch-section of the fan module fail-safe shaft was also missing. As the fan module separated, it cut a spiral path through the inlet ("S") duct and struck the left side of the fuselage about 9 feet forward of the engine's front flange. The module then cut through the aircraft fuselage, leaving a clear cruciform-type impact mark at the upper right-hand side of the "S" duct.

The fan module created a 40- by 20-inch hole on the left side of the aft upper fuselage "S" duct and a 75- by 86-inch hole on the right side of the duct as it passed through. The rear pressure bulkhead was punctured in 10 places, with dents and scratches over a 4-foot-square area. The aft center "C" lavatory was damaged slightly. A 6-inch piece of a 1-inch-diameter steel rod, used to support the "S" duct, was found on the floor of the lavatory. The rear pressure bulkhead below the cabin floor level was not damaged. The "S" duct was damaged internally from next to the fan blades forward about 16 feet. Holes in the "S" duct coincided with the holes in the fuselage.

Holes were punctured in the top surface of the horizontal stabilizer center box beam. There was a hole in the forward spar web, but no holes in the rear spar. The left stabilizer contained about 18 holes in the top surface and 2 holes in the lower surface. The damage pattern was from the top to bottom. The right stabilizer was not damaged.

Hydraulic Systems--There was damage to the components of hydraulic systems A, B, C, and D. The A system return line from the rudder had been punctured below and to the left of the main bleed air duct. The up and down lines on the A system stabilizer actuator were punctured. The B system pump pressure and supply lines, which ran outboard and below the bleed air duct, were dented in numerous places; however, they were not punctured. Both lines on the B system stabilizer actuator were damaged extensively and torn. The B system pump supply firewall shutoff valve was in the open position. The C system pump supply line had several dents; however, there was no leakage. The C system pump supply firewall shutoff valve was in the closed position. The pump pressure line was not damaged. The extend and retract lines between the servo and the stabilizer actuator were dented 18 inches above the servo unit; however, there were no punctures or leaks. The retract line on the D stabilizer actuator was broken at the 90° elbow, three-fourths of an inch below the weld. There was a dent on the line about 10 inches above the break. The A, B, and D system fluid reservoirs were empty while the C system reservoir was full. The B system brake pressure gage was 1,100 psi, and the C system brake pressure gage was 2,200 psi.

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Right side - Inlet "S" duct damage 75 by 86 inch hole.

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Left side - Inlet "S" duct damage 40 by 20 inch hole.

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Internal "S" duct damage after No. 2 engine was removed.

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Holes in aft pressure bulkhead.

Flight Controls--The left-side rudder trim cables were severed and the right-side rudder control cables were jammed by the "S" duct as it was forced outward to the right. The "S" duct was jammed between the stabilizer front spar and the pressure bulkhead. After the "S" duct was removed, the rudder system operated normally. Only the B system stabilizer actuator was damaged extensively. All stabilizer actuator shear pins were intact. The horizontal stabilizer was positioned to 0°. The right-side servo feedback rods were bent.

Electrical--The six generator feeder cables on the left side were damaged in numerous places. Insulation was torn and abraded and a cable was cut about 50 percent through its diameter. All of the small electronic wire bundles on the left side of the fuselage were severed.

The throttle control cables for the No. 2 engine on the left side were severed. The bleed air duct on the left side was punctured in two places and dented in numerous places. One of the two temperature overheat sensor wires was broken.

Engine Fuel System--The No. 2 engine fuel supply line was punctured in two places forward of the primary electrically operated fuel shutoff valve. Both the primary and the secondary fuel shutoff valves were found in the open position and their electrical lines were severed. The electrically operated fuel shutoff valve at the rear wing spar was in the closed position.

1.4 Other Damage

None.

1.5 Personnel Information

The flightcrew consisted of a captain, first officer, and flight engineer. All were properly certificated and qualified for the flight. Eight flight attendants were aboard the aircraft. (See appendix B.)

1.6 Aircraft Information

The aircraft a Lockheed L-1011-385-1 (N309EA), was certificated, equipped, and maintained in accordance with Federal Aviation Administration (FAA) requirements. Three Rolls Royce RB 211-22B engines, which develop 42,000 pounds of static thrust each, were installed on the aircraft. (See appendix C.)

The gross weight of the aircraft was about 405,000 pounds at takeoff, and the center of gravity was within limits. At takeoff, the aircraft had about 87,000 pounds of jet~A fuel on board.

1.7 Meteorological Information

The surface weather observation for John F. Kennedy International Airport at the time of the accident was: 800 feet scattered clouds, 4,500 feet overcast; visibility--5 miles; temperature -- 74°F; dewpoint -- 68°F; wind -- 171° at 4 knots; altimeter setting -- 29.96 inHg.

1.8 Aids to Navigation

There were no reported difficulties with aids to navigation.

1.9 Communications

There were no reported communications difficulties.

1.10 Aerodrome Information

Newark International Airport and John F. Kennedy International Airport were fully operational at the time of the accident, and there were no reported difficulties with either aerodrome facility.

1.11 Flight Recorders

As required, the aircraft was equipped with both a cockpit voice recorder (CVR) and a digital flight data recorder (DFDR).

A Fairchild CVR tape was brought to the Safety Board's Audio Laboratory for examination and transcription. The tape started with the aircraft on final approach 20 minutes after the incident. Since the recorder's capacity is 30 minutes, there was no information pertinent to the incident on the tape. The audio quality of the tape was excellent.

The DFDR was processed at the Safety Board's Flight Data Recorder Laboratory. The recorder indicated the following information just before the engine failure:

Altitude:	10,808 feet
Indicated Airspeed:	304 knots
Heading:	127°
Pitch:	2.2° nose up
Roll:	2.1° left wing down
Engine Exhaust Pressure Ratio (EPR):	1.4437 (No. 1)
	1.4745 (No. 2)
	1.4261 (No. 3)

Immediately after the accident, the No. 2 engine EPR reading went momentarily to zero and then rose to the high stop and remained there for the duration of the flight.

1.12 Wreckage and Impact Information

The fan module, which separated from the fan shaft and broke through the "S" duct, fell in the Atlantic Ocean and could not be recovered.

1.13 Medical and Pathological Information

Not Applicable.

1.14 Fire

The in-flight engine fire had extinguished by the time the aircraft was landed.

1.15 Survival Aspects

The accident was survivable; there were no deaths or injuries.

1.16 Tests and Research

1.16.1 Powerplants and Metallurgical Examination

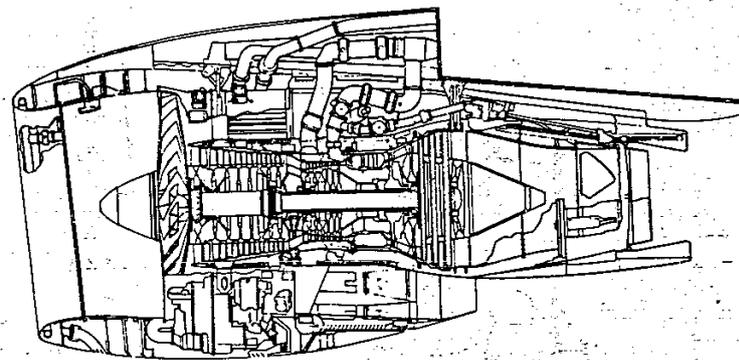
The RB-211 engine is manufactured by Rolls-Royce, Ltd., at Derby, England. Engine power to propel the Lockheed TriStar (L-1011) aircraft is provided by three RB-211 engines. One engine is attached by a pylon to the underside of each wing with the third positioned in the rear of the fuselage below the vertical stabilizer. Each three-shaft, turbo-fan type engine consists of a single-stage fan mounted on a separate shaft driven by a two-shaft gas generator. Engine thrust is produced from two separate streams--airflow from the fan and exhaust from the gas generator. The fan airflow produces about 75 percent of the total thrust.

The engine has six rotating assemblies: the low-pressure compressor (LPC) rotor or fan, the intermediate-pressure compressor (IPC), the high-pressure compressor (HPC), the high-pressure turbine (HPT), the intermediate-pressure turbine (IPT), and the low-pressure turbine (LPT). ([See figure 2.](#))

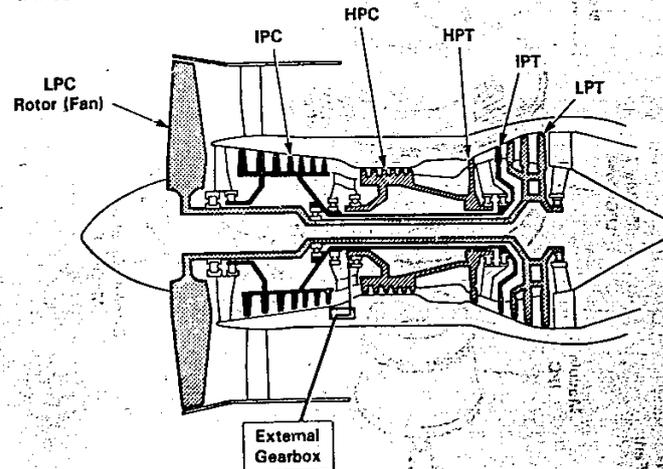
Engine Modules--The engine has been designed to break down into seven major modules. These are: ([See figure 3.](#))

Engine Component	Module No.
LPC rotor (Fan)	01
IPC	02
Intermediate Module	03
High Pressure System	04
IPT & LPT Assemblies	05
External Gear Box	06
LPC Case	07

Under the supervision of the Safety Board, the No. 2 engine was disassembled and closely examined at Eastern Airlines' John C. Ray Engine Service Center, Miami, Florida. The investigation consisted of conducting a borescope examination of the high-, intermediate-, and low-pressure turbines, determining the axial positioning of the intermediate- and low-pressure turbines, testing the electrical continuity of the airborne vibration monitoring system, and removing the various engine fuel and oil pipes and engine operating accessories. The engine fuel system components were functionally tested. The fuel and oil pipes were checked for blockages or obstructions. The engine was disassembled by separating the seven basic modules and the modules were disassembled to determine and document the condition of their parts. Pertinent torques and engine-build dimensions were measured for each module and, where applicable, were compared to the engine manufacturer's overhaul limit specifications. Pertinent modules were tested for either oil pressure or oil passage flow. A description of each component and the details of these examinations and tests follow:



Propulsion System General Arrangement



Main Rotating Assemblies

Figure 2. -- Propulsion System General Arrangement and Main Rotating Assemblies.

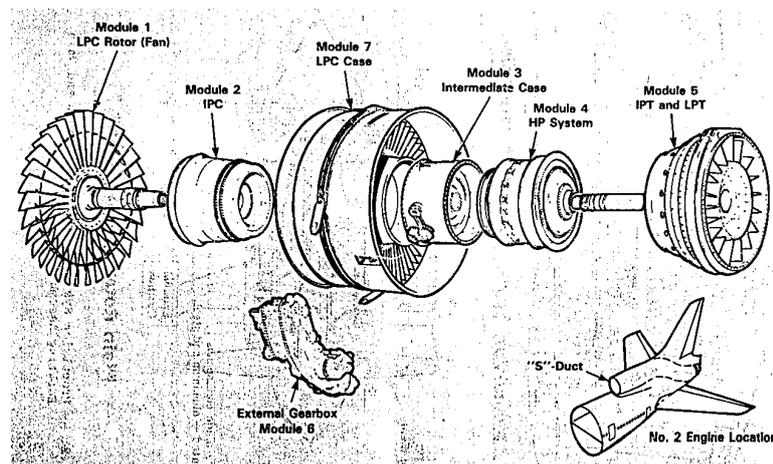


Figure 3. -- Module Breakdown of Engine.

Low-Pressure Compressor (LPC) Rotor (Fan) Module (01)--Thirty-three titanium blades are fitted to the titanium compressor disc which is streamlined by a large rotating nose bullet. The LPC shaft is supported by a roller bearing and a ball thrust bearing and the shaft passes through the IPC. It is splined and locked to the LPT shaft.

The fan shaft separated in the shaft's reduced section area about 0.8 inches forward of the rearmost cooling air passage holes. The recovered portion of the fail-safe shaft, located concentrically within the fan shaft, had localized heat damage. The fail-safe shaft had fractured at the rearmost cooling air passage holes in the same relative area as the fan shaft. The characteristics of the surface of the fail-safe shaft fracture were moderately irregular, jagged in appearance with tensile necking down, a small degree of torsion, and localized overheating. The most severe heat discoloration was

noted in the plane of the cooling air passage holes. The tubular bolt for the fail-safe shaft and the bolt's retaining nut exhibited localized areas of heat discoloration.

IPC Module (02)--The IPC is a seven-stage axial flow compressor. A ring of fixed inlet guide vanes supports the front bearing housing. Both the LPC and IPC roller bearings are located in this housing. Services transferred through these guide vanes are oil feed and scavenge, air vent and LP/IP rpm indication wiring.

The outer pivot arm bushings to the front bearing housing assembly's variable inlet guide vane were either missing or were dislodged from their installed positions, as a result of the engine failure. The outer two-fifths of the leading edges of the intermediate-pressure compressor rotor blades and vanes were damaged by hard foreign objects; the damage consisted of heavy gouging and tearing. The damage was most severe at the stage 1 airfoils and gradually diminished in intensity and became more random in the aft compressor stages.

The sealing material installed inside the curvic coupling seal of the intermediate-pressure compressor rear stubshaft was heavily rubbed; the heaviest rubbing and metal-to-metal contact was over 120° of the seal's internal circumference. The rubbing resulted from the seal material's contacting the rotating fins of the low-pressure location bearing air and oil seal.

The intermediate-pressure compressor curvic coupling seal lip had a heat-induced lobe that was about 2.5 inches in circumference by about 0.5 inch in height. The area adjacent to the lobe was discolored by heat and the lobe's seal area was heavily rubbed. Some of the sealing liner remained within the interior surface of the lobe.

Intermediate Module (03)--The IPC case is constructed of aluminium alloy in the forward section and steel in the rear. The material of which the stator vanes in the case are made corresponds to the material of the section of the case in which the vanes are located -- aluminum and steel.

The compressor rotor shaft has five titanium discs in the forward section and two steel discs forming the rear section. Titanium rotor blades are used throughout. The rear stub shaft is splined and locked to the IPT shaft. (See figure 4.)

The front air seal knife edge fins of the low-pressure location bearing (LPLB) air and oil seal were rubbed down to about 50 percent of their normal height; the fins had rubbed against the IPC rear stubshaft coupling.

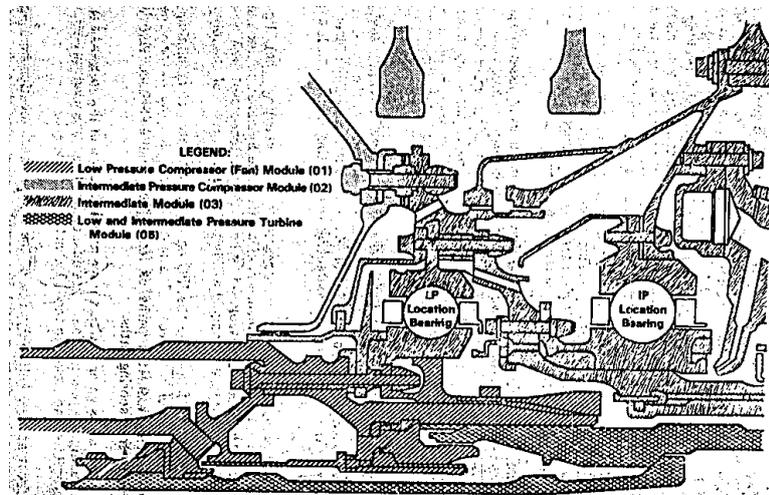


Figure 4. -- RB-211-22B Module Arrangement.

The front and rear faces of the hydraulic seal fin were rubbed; the front face was rubbed by the piston ring seal housing to about 0.600 inch from the fin tip. The rear face was rubbed by the front face of the LPLB ball cage.

A heavy rub had occurred between the male member of the LPLB air and oil seal assembly and the locating land of the ring seal. The ring seal had also rubbed and had been forced into its ring seal locating groove, fusing it into the ring seal carrier housing.

The outer surface of the LPLB ring seal housing was heavily heat damaged and was dry. Heat produced by the rubbing had discolored the inner diameter of the ring seal housing. Heat discoloration was greatest at the housing's inner portion near the ring seal. The piston ring was seized in its seal locating groove. Evidence of oil leakage was observed between the abutment faces of the IPC rear stubshaft and the LPLB oil weir and between the abutment faces of the intermediate pressure location bearing (IPLB) inner race front flange and the IPC rear stubshaft.

The low-pressure location bearing had deteriorated from intermittent spalling of the bearing's outer race that encompassed 250° of its circumference. The area of apparent fatigue spalling was biased toward the rear side of the

bearing's race track. The profile of the LPLB's inner race track was worn heavily and was elongated axially to a width of 1.250 to 1.375 inches; the forward and rear lands of the inner race adjacent to the track profile were also heavily worn. The bearing cage was extensively overheated. The bearing location lands were worn and the bearing cross grooves were filled with debris. The front half of the bearing cage was heavily rubbed on its front face from contact with the base of the hydraulic seal fin. Molten material produced from the inner track/ball wear and breakup had been deposited onto the front half cage bore for 160° of its circumference. The edge ball pockets were heavily worn. The rear oil catcher lip was distorted rearward from rear and rearward movement of the inner race; it had come in contact with the retention bolt heads of the low pressure location bearing oil weir. The main surface areas of the location bearing balls showed minor primary skidding type damage with wear ranging between 0.007 to 0.012 inches on the diameter of the ball. The individual ball's wear pattern was uniform and the balls generally maintained their sphericity. None of the balls had any visual appearance of secondary fatigue. All of the balls had randomly located sliding flats, some of which were reoriented. The flats' approximate diameter ranged from .125 of an inch to .75 of an inch; these flats could be related to the inner race movement in the fore and aft thrust directions.

The oil scavenge cavity located in the intermediate pressure compressor rear stubshaft contained a mixture of metal and oil sludge in the scalloped area of the cavity, although none of the oil scavenge holes was clogged. The mating abutment faces of the rear stubshaft of the IPC and the inner race front locating flange of the intermediate pressure location bearing exhibited paths of leaking oil and embedded fine metallic particles which had formed scoring paths.

The mating abutment faces of the LPLB oil weir and the IPC rear stubshaft also contained embedded fine metallic particles, particle scoring paths, and oil-stained leakage paths. Oil passages were not clogged.

The securing bolts to the IPLB outer race were stretched; the head of one bolt had separated. As a result of stretching, a gap had been created between the bolt heads and the IPLB outer race. The opening was 0.0015 inch at its narrowest separation and 0.050 inch at its maximum separation. The sealing bore for the IPLB support flange was rubbed by the rear stubshaft rotating fins of the IPC.

An airflow test was performed on the intermediate module oil system with no significant findings. An oil-jet test was performed with the oil jet undisturbed and the intermediate pressure location bearing in its installed position. The oil jet flowed at pressures up to 50 psig; 100 percent of the oil-jet flow was ejected under the IPLB inner race flange.

The internal gearbox assembly static-air and oil-seal lining was worn as a result of contacting the high-pressure compressor stubshaft assembly air and oil seal fins. All of the seal fins had been rubbed over their entire circumference and the rub was about 0.010 inch deep. The abradable lining of the internal gearbox oil collecting sleeve had been heavily rubbed by the rotating seal fins of the IPT shaft.

High-Pressure System Module (04)--This system is made up of the HPC, the combustion chamber and outer case, and the HPT. The six-stage axial flow compressor casing is formed by steel flanged rings which house the six rows of steel *[sic]*. The drum-type rotor is built from titanium and steel discs with titanium rotor blades for the first three stages and steel for the remainder. The combustion section consists of a fully annular chamber fitted with 18 spray nozzle assemblies, 2 of which incorporate high energy igniter plugs.

The leading edges of all the high-pressure compressor blade airfoils were heavily damaged by foreign objects. The blades trailing edges were less damaged by foreign objects than were their leading edges. The blade airfoil damage became progressively less severe in the latter stages of the high-pressure compressor. The stator vanes and cases were also damaged. The stator vanes and blades were splattered with aluminum debris and were oil-coated.

The high-pressure turbine nozzle guide vanes had a heavy buildup of metallic splatter on their concave surfaces and on the leading edges. The metallic splatter was fused onto the vanes and had blocked some of the cooling air holes. The high-pressure turbine blades were intact and were not damaged, except for a fused metallic buildup on the leading edges and concave sides.

Low- and Intermediate-Pressure Turbine Module (05)--The roller bearing for the single-stage IPT is located in the same housing as the HPT bearing. This housing is supported by a fabricated steel structure which passes through the IPT nozzle guide vanes to attach to the IPT nozzle case. The first-stage low pressure nozzle guide vanes are also housed in this case. A separate LPT nozzle case is used to house the second- and third-stage low pressure nozzle Guide vanes.

An *[sic]* to the rear of the LPT nozzle case and contains a support structure of 18 *[sic]* struts and an LPT bearing hub. This bearing supports the three-stage LPT *[sic]* assembly.

Externally, the entire module was intact and was not damaged. The only discrepancies observed *[sic]* secondary metal deposits on the outer third of the concave sides and under the shrouds of the intermediate-pressure turbine blades, all of the blades exhibited metal splatter and leading-edge roughness. The low-pressure turbine seal segments exhibited heavy axial and radial rubs.

The low-pressure turbine blade airfoils were intact and were not damaged. There was no evidence of any unusual wear on any of the blade tip seals, indicating that no significant low-pressure turbine disc overspeed had occurred. The low-pressure turbine stage 1 disc bore and outside diameter were within specified limits, also indicating that the disc had not

been subjected to a significant overspeed condition.

External Gearbox (06)--The external gearbox, including the engine oil system tank, is mounted on the lower left-hand side of the LPC case. It provides drives and mounting positions for the following units:

front face	- oil pumps air starter hydraulic pumps (2 positions)
rear face	- fuel pumps fuel regulator N ₃ indicator generator integrated drive generator

The gearbox was examined and was found to be in normal condition.

LPC Case Module (07)--Two circular cases extend from the engine intake to the firewall diaphragm. The front section is steel and is thickened opposite the compressor rotor blade tips to form a blade containment ring. Titanium is used for the rear section and steel outlet guide vanes are bolted to it. The inner ends of these Guide vanes are welded to a steel case which surrounds and supports the LPC. Two piston-type bleed valves are located on the steel outer support case and when open will bleed air from the last stage of the IPC. The LPC case module attrition liner was intact but slightly damaged. There was no other damage to the module.

Oil System--All of the engine oil pressure, scavenge, and vent pipes were flushed out in order to determine if any of the pipes leaked or contained any foreign debris. None of the pipes were found to leak, two of the oil pipes contained foreign debris. The debris was failure-generated, carbon-like and metallic materials from within the engine.

Metallurgical Examination--The No. 2 engine low-pressure location bearing and associated components, a section of fractured fan shaft, a section of fractured fail-safe shaft, and the fan shaft thrust ring were examined at the Safety Board's metallurgical laboratory.

Metallurgists determined that the fan shaft had separated as a result of torsional overstress while subjected to localized heating at temperatures above the transformation temperature of the material 730° C (1350° F).

The LPLB contained massive mechanical damage which allowed excessive axial and radial movement within the bearing assembly. Rubbing *[sic]* associated components *[sic]* consistent with the excessive axial and radial movement produced by the failed bearing assembly.

1.17 Aoditional Information

1.17.1 Low-Pressure Location Bearing

The RB-211 low-pressure spool is supported on two roller bearing, one at the LPT and the other just aft of the fan, and a ball bearing near the shaft *[sic]* in the IPC case. The ball bearing reacts to all low-pressure pool thrust loads and is called the low-pressure location bearing (LPLB). The LPLB constitutes an intershaft bearing between low-pressure and intermediate-pressure spools, and thus at maximum takeoff thrust the inner race rotates at 3,880 rpm and the outer race at 7,140 rpm (clockwise from the front). Both races and the 15 balls are made of hardened high strength tool steel (18 percent tungsten, 4 percent chromium, 1 percent vanadium). This is not a highly corrosion-resistant material. Normal hardness is Rockwell C 40 and melting point is 1,510 °C. Normal LPLB operating temperature is about 240°C. The two-part bolted bell cage is made of silver-plated low alloy steel. Overall diameter of the bearing is about 14 inches and each ball is 1.1039 inches in diameter. [\(See figure 5.\)](#)

1.17.2 Lubrication System

Nominal total lubrication system capacity is 38.7 quarts of oil, including 23.7 quarts in the tank; consumption is 0.95 quarts/hour. A single-gear pump in the external gearbox supplies pressurized oil to the engine via a pressure filter. If the filter becomes blocked, the element is bypassed automatically and the engine oil filter pressure warning light illuminates on the flight deck. Low-pressure and intermediate-pressure location bearings are supplied by a single oil jet. (See [figure 6](#)) This jet sprays oil toward an annular slot formed between the IPC stubshaft and the IPLB inner race; typical catch efficiency is 60 percent for the RB-211 engine. Under centrifugal forces, part of the oil entering the slot passes outward through a passage in the IPLB inner race to supply the bearing; the remaining oil passes forward and outward to a weir through holes in the IPC stubshaft and in the weir flange. The oil supply must cross the two flanged joints between the IPLB inner race and the rear IPC stubshaft and between the stubshaft and the oil weir to reach the weir. A lip on the aft side of the LPLB cage catches oil being thrown outward after spilling over the weir lip for LPLB lubrication. Cage passages distribute oil within the bearing.

Oil leaving the LPLB collects in a centrifugal sump in the area of the LPLB outer race. Oil leaves this sump through overspill holes in the IPC stubshaft arranged to maintain a constant sump depth. In addition, these holes are angled to form a hydraulic trap air seal between the LPLB chamber and the remainder of the gearbox. Oil leaving the sump through the overspill holes joins other scavenge flows in the gearbox and is returned to the tank by one of the four scavenge pumps through a magnetic chip detector and strainer, and the fine scavenge filter.

1.17.3 Airborne Vibration Monitoring (AVM) System

The AVM system continuously senses and indicates engine vibration levels and provides a visual warning of excessive vibrations or an out-of-balance condition in the main rotating assemblies. Each engine has two vibration accelerometers, one mounted on the fan and the other mounted on the turbine casing. A push-button switch (FAN) selects the fan transducer for all engines, and a second push-button switch (TURB) selects the turbine transducers for all engines. The switches should not be selected simultaneously since erroneous readings would be displayed. Transducer output signals pass through junction boxes in the interservice fairing to an airframe mounted condition monitoring unit where they are filtered to remove extraneous frequencies and smoothed. A single control, the broad band vibration filter selector, selects one of four frequency bands for all three engines:

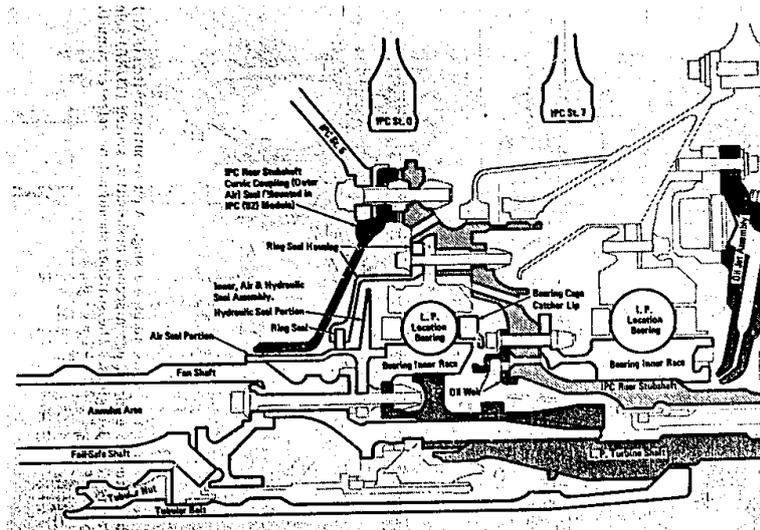


Figure 5. -- Installed Position of Components Associated with LPLB Failure.

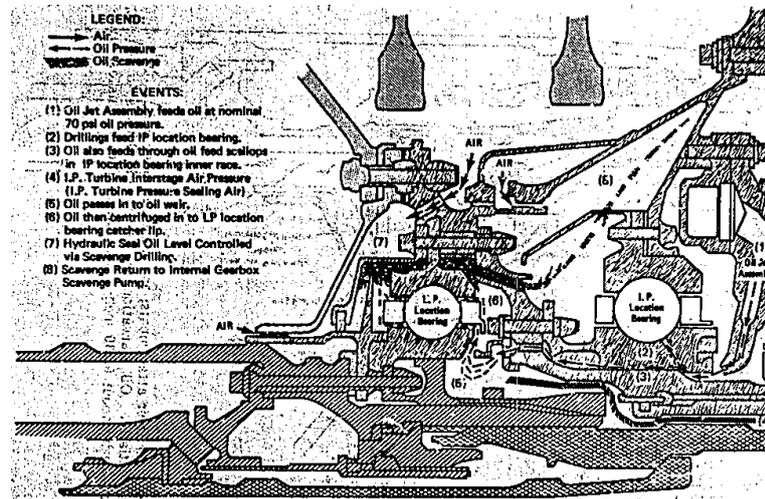


Figure 6. -- LPLB Normal Oil Supply and Scavenge.

Selection:

N_1 - Corresponds to low-pressure rotor rpm (100% = 3,900 rpm. 99.5% at maximum take off (MTO) thrust)

N_2 - Corresponds to intermediate-pressure rotor rpm (100% = 7,000 rpm. 102% at MTO thrust)

N_3 - Corresponds to high-pressure rotor rpm (100% = 10,611 rpm. 95% at MTO thrust)

NORM - Broad band filter covering N_1 , N_2 , and N_3 range of 3,000 to 11,000 rpm.

Filtering is effective from just below cruise to takeoff rpms. The spool frequency filters enable an out-of-balance spool to be identified by selecting each band in turn. All controls and indicators are on the second officer's panel, and on this L-1011 excessive AVM signals also illuminate the single latched amber status caution light on the pilot's caution and warning panel. This feature was deleted on many Lockheed aircraft by Lockheed Optional SB 093-77-039 because of AVM reliability. Since the recent accidents, further AVM modification has been initiated to increase reliability.

Almost all of the preaccident AVM system malfunctions manifested themselves by large fluctuations in gauge indication, frequently as a result of intermittent open circuiting of transducer leads. If the circuit opened permanently, the gauge would indicate zero and the caution light would not illuminate.

1.17.4 Failure History

Since the RB-211 engine was introduced to airline service in June 1971, there have been 259 LPLB in-service failures as of April 4, 1982, in about 10 million hours of engine operation. Fleetwide statistics for 1981 indicate 0.024 LPLB failures per 1,000 operating hours. Comparable bearing failure rates for the Pratt and Whitney Aircraft JT9D and the General Electric CF-6 engines are 0.001 per 1,000 operating hours. Since November 1978, there have been seven known cases of fire in the area of the LPLB as a result of bearing failure. There was shaft overheating in six instances and the shaft failed in three cases, including this instance.

There have been two previous similar fan shaft failures. The first, on May 25, 1981, involved an Eastern Airlines L-1011's No. 3 engine failure. The circumstances were similar to this accident, except that the LPT rotor assembly oversped and released stage 1 turbine blades from their attachments; the released blades completely ruptured the LPT case circumferentially. Oil starvation caused the LPLB balls to rub together which reduced their size by about 0.130 inch in diameter. The ball material was redeposited onto both the inner and outer races.

The second incident, on August 10, 1981, involved a Delta Airlines L-1011's No. 3 engine. The LPT rotor assembly also oversped and released the stage 1 turbine blades; the released blades completely ruptured the LPT case circumferentially in a manner similar to that experienced in the Eastern incident; however, in the Delta incident, the fail-safe shaft retained the fan module. The LPLB exhibited characteristics similar to those shown in this accident.

Rolls Royce reviewed all previous LPLB failures and categorized 44 as severe. Of the 44 severe failures, there were 18 suspected incidents of overheated fan shafts. Therefore, the manufacturer selected 10 engines that had suspected fan shaft overheats (failure or softening) for detailed investigation. They are:

Engine Serial No.	Airline	Date	Comment
10101	Eastern	9/22/81	LPLB failure with oil fire in flight. Fan shaft failure resulting in loss of fan module.
10356	Eastern	5/25/81	LPLB failure with oil fire in flight. Fan shaft failure resulting in loss of fan module.
10576	Delta	8/10/81	LPLB failure with oil fire in flight. Fan shaft failure but fail-safe shaft retained module.
10206	Eastern	3/15/80	Fan shaft softening.
12024	British	8/12/78	Fan shaft softening.
14025	Saudia	6/24/81	Fan shaft softening.
10103	Eastern	7/5/81	LPLB failed one hour after repair. ⁴
10197	Transworld	6/2/81	LPLB failure with oil fire. Fire to rear of 03 module. ⁴
10080	Eastern	7/19/81	Flash fire in turbine shaft on EAL test stand. ⁴
10627	Eastern	9/7/81	LPLB failure in flight. ⁴

⁴Fan shaft was not softened by fire.

For the 10 selected engines, Rolls Royce conducted an extensive study of possible causal factors. These included engine/module component history, modification standards, designated engine disassembly reports, flight log and line maintenance data, test-cell history, on-wing performance history, and operational procedures. A life history of each module by serial number from 0 time to the present was completed on the 10 engines and all reportable events identified. The various modification standards incorporated since the engines were new were determined in addition to specific changes incorporated in each module at its last shop visit. Disassembly reports were completed. Events associated with the flight data logs and line maintenance reports were reviewed. An analysis of the test-cell history of the failed engines was completed; all of the engine parameters were within normal data-scatter bands. The manufacturer concluded that the study did not reveal any abnormal or unacceptable condition that would cause or contribute to the types of failures that were experienced.

The engine manufacturer's test results indicated that there are negligible differences on bearing loading when takeoff

power is applied to an engine that has just been started when compared to bearing loading after the engine has been operating for several minutes. The engine manufacturer indicated that a pretakeoff warmup is beneficial to engine performance and has recommended that the operator employ specific minimum engine warmup periods before takeoff (5 minutes for cold engines, 3 minutes for *[sic]*).

Of the 10 selected engines, 8 had steel intermediate cases. (A majority of the in-service engines are equipped with steel intermediate cases; therefore, the exposure for steel cases is high.) The engine manufacturer has not been able to associate the steel intermediate case configuration with the LPLB failures and oil-generated fires. Failures have typically occurred shortly after shop maintenance; eight of these failures occurred within 400 hours after the engine module's last shop visit. These failures have not necessarily involved intermediate module disassembly, and the manufacturer has not been able to correlate these low operational times with the subsequent failures.

The engine manufacturer has completed a page-by-page comparison of shop maintenance procedures used at Eastern Airlines with Eastern's overhaul manual, the engine manufacturer's overhaul manual, and new engine maintenance instructions. The comparison covered procedures for IPC rear stubshaft and bearing assembly and the intermediate case buildup required to complete the intermediate case module. Additionally, the comparison covered the removal and refit procedures for the fan module, the high-pressure system module, and the low- and intermediate-pressure turbine module, including any necessary powerplant operations.

The only differences noted in this comparison were: (1) the engine manufacturer's Service Bulletin 72-4402, which specifies installation of a bevel box steady bracket for the high-speed gearbox drive for the steel intermediate case, had been deleted from Eastern's overhaul manual; (2) Eastern's overhaul manual specifies Loctite joint compound to be used on the LP and IP location bearing's outer race flange bolts; and (3) Eastern's Work Control Directive specifies "OMAT.26" joint compound on the LP location bearing outer rear flange. The engine manufacturer stated that the only relevant difference found is that the engine manufacturer's and Eastern's overhaul manuals call for Loctite joint compound on the LP and IP location bearing outer race flange bolts while the manufacturer's engine maintenance instructions do not.

1.17.5 Flightcrew Instructions

The section of the Eastern Airlines L-1011 Flight Manual in effect on September 22, 1981, pertaining to powerplant abnormal procedures states:

ENGINE VIBRATION

If other evidence of engine malfunction or significant increase in airframe vibration substantiates AVM indications:

ENGINE SHUTDOWN

Do not relight unless a greater emergency exists.

During steady running conditions, vibration level limits are:

- o 2 1/2 units (warning lights illuminate), or
- o Sudden increase of 1 unit or more.

If no evidence of engine malfunction or significant increase in airframe vibration substantiates AVM indications:

FILTER SELECTOR NORM

Compare FAN and TURB pickup indications separately.

Indicates failure of engine rotating assembly.

If both pickups confirm high vibration:

THROTTLE REDUCE TO IDLE

If vibration level on both pickups follows the power change:

ENGINE SHUTDOWN

Do not relight unless a greater emergency exists.

OIL FILTER PRESSURE LIGHT ON

The FILTER PRESSURE light indicates oil filter clogging. This may or may not be the result of a mechanical failure.

ON GROUND

Takeoff prohibited.

Call Maintenance for investigation.

IN FLIGHT

OIL PRESSURE MONITOR

OIL QUANTITY MONITOR

AVM MONITOR

If normal:

Record and report.

No further action necessary.

The following temporary revision No. 16 was issued by Eastern Airlines on October 16, 1981:

BACKGROUND

In September, Eastern experienced its second RB211 engine inflight fan shaft failure, the third such incident to occur on L-1011 aircraft industry-wide recently. Although the cause of these failures has not yet been positively determined, all incidents were preceded by abnormally high engine vibration detected on the AVM. This TR reflects mandatory revisions to procedures and system requirements per Airworthiness Directive T81 21/51. These procedures and requirements are intended to promptly alert the flight crew to indications of possible impending engine failure and immediate actions required to investigate the incidents and further rulemaking is expected.

SYSTEM REQUIREMENTS

The following must be operating for dispatch:

- The complete AVM system.
- All oil FILTER PRESSURE lights.

NORMAL OPERATING PROCEDURE

Prior to takeoff, the FAN Pickup Selector mus be latched in (ON illuminated) with the TURB Pickup Selector out (ON extinguished). The Filter Selector must be in the NORM position.

NEW EMERGENCY PROCEDURE

ENGINE VIBRATION

During steady running conditions,
If the AVM indicates a sudden increase
of 1.0 unit or more, or exceeds 2.5 units
(warning light setting)

This applies even if the excursion
above limits is of short duration
with the indication returning
to normal.

IMMEDIATE ACTION

THROTTLE REDUCE TO IDLE

ENGINE SHUTDOWN

Do not attempt engine restart unless
greater emergency exists.

When holding or descending in
heavy icing conditions, the AVM
may gradually increase to as much
as 2.5 units (warning lights setting).
No action is required unless there
are other indications of engine
malfunction, in which case the
engine must be shut down. Vibration
due to icing can be alleviated
by the use of 90% N_1 for 5 seconds.

NEW ABNORMAL PROCEDURE

AVM SYSTEM MALFUNCTION

If the FAN channel becomes Inoperative:

FAN PICKUP SELECTOR OUT

TURB PICKUP SELECTOR IN

If total loss of AVM indication for one engine
occurs:

ENGINE SHUTDOWN

Unless a greater emergency exists.

NEW EMERGENCY PROCEDURE

OIL FILTER PRESSURE LIGHT
ILLUMINATES STEADILY

IMMEDIATE ACTION

THROTTLE REDUCE TO IDLE

ENGINE SHUTDOWN

Do not attempt an engine restart unless a greater emergency exists.

2. Analysis

The aircraft was properly certificated and had been maintained in accordance with approved procedures. The differences in build procedures between the operator's and the engine manufacturer's overhaul manuals were not significant. There was no evidence of preaccident failure or malfunction of the aircraft systems, structure, or flight controls. The flightcrew was properly certificated and qualified for this scheduled international passenger flight. They held current medical certificates. Weather was not a factor in this accident.

2.1 Flightcrew Actions

The flightcrew's immediate reaction to the AVM light was to reduce power on the No. 2 engine to near idle. The second officer used the broad band vibration filter selector to check vibration in the different sections of the engine. N_1 and N_3 were normal. N_2 , corresponding to the intermediate pressure compressor, was high and off scale. At that time, the oil filter pressure warning light illuminated, but all AVM readings were normal and stayed normal for the rest of the flight. Consequently the oil filter pressure light was the only remaining system to warn of impending engine failure.

The Safety Board believes that had other clues of impending engine failure occurred, such as constant or steady indications of AVM off-scale or in excess of 2 1/2 units, the associated amber AVM warning light, loss of engine oil pressure and/or engine oil quantity, significant increase in airframe vibration, loss of engine rpm and thrust, rapid decrease or increase in exhaust gas temperature or N_1 , N_2 , N_3 rpm rotor overspeeds or decreases, the flightcrew would have immediately shut down the No. 2 engine. However, since those clues of impending engine failure were not in evidence, the crew reacted to available cockpit engine instrumentation readings and events as they occurred, and the Safety Board concludes that the flightcrew acted in accordance with the appropriate procedures in existence at the time of the accident. Flight manual procedures and minimum equipment list requirements which were modified on October 16, 1981, expanded flightcrew procedures for an AVM event or a oil filter pressure warning light and required a completely operative AVM system for flight. These procedures and requirements were made mandatory for all operators by FAA airworthiness directive on February 11, 1982.

2.2 Engine Failure Sequence

The initiating event in the LPLB failure was an inadequate oil supply to the bearing because of oil leaks between abutment faces of the IPC rear stubshaft and the LPLB oil weir and leaks between the abutment faces of the LPLB inner race locating flange and the IPC rear stubshaft. Each of these interfaces had evidence of oil leakage path stains and foreign debris entrapment. (See figure 7.) The LPLB oil supply system does not provide a positive oil feed to the bearing, but rather a "slinger" type is used to lubricate the bearing. Since the oil supply jet was not positive and since leaks occurred across the flanged abutment faces, probably as a result of poor mating of these surfaces following overhaul, the LPLB inner race flange may have become distorted at high power settings. The Safety Board believes that the "slinger" oil supply and oil leaks at the abutment faces are major factors in LPLB distress situations.

The inadequate supply of oil allowed the LPLB assembly to overheat and provided a temperature high enough to induce bearing outer race fatigue spalling, which in turn would have induced ball tightening and rubbing in the bearing cage pockets. The bearing cage and the bearing inner race lands also would have rubbed together, causing the cage to expand. These factors, in addition to high centrifugal force loadings, would allow the balls to grind and skid. The condition of the bearing's inner race and balls indicated that the balls were skidding and grinding into the bearing's inner race track in both the fore and aft directions, as shown by the contour match of the balls relative to the bearing's inner race track.

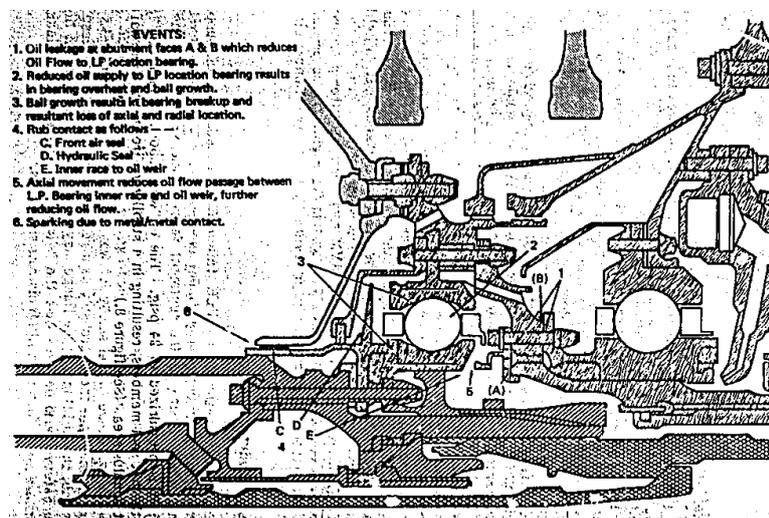


Figure 7. -- Initial Failure Sequence.

The predominant wear and damage pattern occurred at the front of the bearing's inner race. This failure pattern indicated that gross ball sliding took place when the engine was operating at a relative low power setting.⁵

Examination revealed that the inner rear face of the LPLB inner race and the forward lip of the oil weir had come into contact; the contact was caused by rearward axial movement of the inner race. These contact marks indicated that the LP system was rotating when the LPLB was displaced rearward. This would have further reduced oil flow between the LPLB bearing's inner race and the oil weir and thereby reduced oil flow to the LPLB itself.

The LPLB failure displaced the IPC rear stubshaft curvic coupling seal members axially and radially from their installed positions, causing heavy rubbing which generated heat among various IPC rear stubshaft coupling seal members. Components softened by the heat include the hydraulic seal fin, the ring seal, the ring seal housing, and the IPC rear stubshaft coupling air seal. The IPC rear stubshaft curvic coupling seal lining was rubbed and grooved to the extent that a dull blue heat-induced lobe was produced. The dull blue color of the seal's metal lining indicated that the heat-induced lobe had been exposed to temperatures near 900° C. This lobe formed a gaseous pathway toward the fan shaft annulus area. The hydraulic seal fin had also been displaced and was rubbed at several places by the LPLB cage, the ring seal, the ring seal housing, and the airseal around the IPC rear stubshaft coupling which resulted in the loss of the hydraulic seal's radial and axial integral placement.

The ring (piston) seal housing and the ring (piston) seal which is adjacent to the hydraulic seal fin were also rubbed heavily. Oil level-type marks present on the rear face of the ring seal housing arm suggest that different levels of oil were present in the ring seal housing/hydraulic seal cavity. The differences in oil levels indicated that the normal capillary-type seal between the hydraulic seal and the ring seal housing had been compromised, thus allowing LPLB oil to eject into the fan shaft area. The oil that escaped was mixed with pressurized air from two sources and was injected into the fan shaft annulus area. The first source was the oil scavenge cavity, located between the LP and IP location

bearings, which is pressurized by 7th stage compressor air to 39 psig with the engine operating at climb power. Additional pressurized air is provided from the IPT pressure seal; it is pressurized to 24 psig. The oil was vaporized and was ignited by contact with the hot seal members, resulting in a stabilized fire in the fan shaft and the fail-safe shaft annulus area. (See figure 8.)

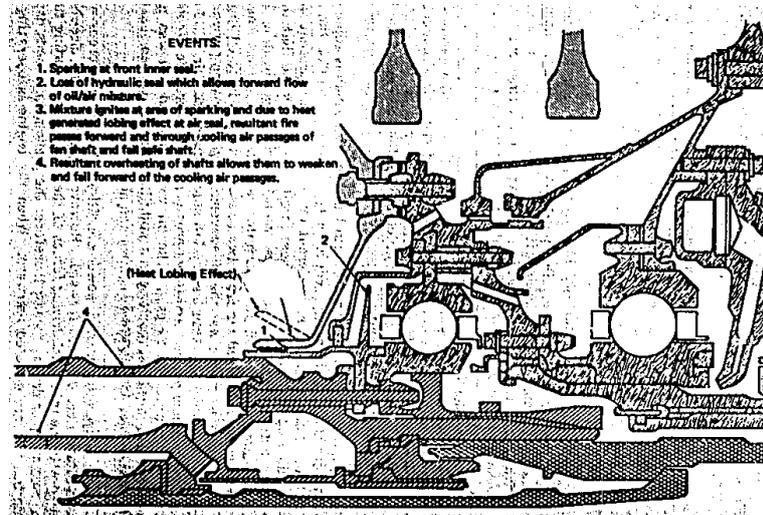


Figure 8. -- Engine Fire Sequence.

The stabilized fire degraded the material properties of the retained section of the fan shaft and caused the shaft to fail in a torsional and shearing mode. The degradation of material properties was evident by the discoloration patterns on the fan shaft fracture surface which indicated that the area adjacent to the fail-safe shaft fracture also reached a temperature probably in excess of 900° C. The recovered section of the fail-safe shaft exhibited rapid tensile/torsional overload fractures which also occurred as a result of exposure to these high temperatures.

As a result of the fan and fail-safe shafts fractures and the separation of the fan module from its installed position, the engine surged. The engine surge apparently resulted from the combination of (1) inlet air flow perturbations caused by the fan module separation after the fan was released from the LPT rotor assembly and (2) the ingestion of separated inlet duct sections. The engine surge apparently prevented the released LPT rotor assembly from overspeeding and disintegrating as it did in the two previous incidents. Instead, the released fan moved forward in the inlet duct about 9 feet before penetrating through the sides of the duct.

2.3 Additional Aircraft Damage

As the fan module moved forward and separated through the right side of the "S" duct, it extensively damaged the aircraft's structure and systems. While the damage, including penetration of the pressurized cabin probably affected the structural integrity of the vertical stabilizer, the penetration area was so small that there was no noticeable degradation of cabin pressure.

The most significant damage which affected the captain's ability to control the aircraft was the disabling of three of the aircraft's four hydraulic systems and the damage to the rudder control cables. The L-1011, like all modern wide-bodied aircraft, depends upon the integrity of some hydraulic services for flight control. Redundancy is built into the system such that each of the four hydraulic systems is independent and each provides partial power to maintain flight control about each of the aircraft's control axes. The systems are physically separated so that normally damage inflicted to a small area of the aircraft will not affect all of the hydraulic systems. A separation of the entire fan module, however, was not considered as a possible occurrence during the design of the airframe and, thus, was not an influencing factor in the placement of redundant systems. The extensive spread of debris from the fan module severed the fluid lines of three of the hydraulic systems. The fourth system sustained a damaged line; however, it was not severed and fluid pressure capacity was retained. The system which remained provided control to the horizontal stabilizer, the inboard ailerons, the rudder, the outboard spoilers, the trailing edge flaps, the leading edge slats, the landing gear, nose wheel steering, and the alternate wheel brake system.

However, since the rudder control cables were jammed, preventing the movement of the rudder pedals, both rudder control and nose wheel steering--the controls for which are interconnected to the rudder control cables--were rendered inoperable. Nevertheless, sufficient flight control was available for the captain to land and stop the aircraft without further incident.

The fan module debris also damaged the electrical wire bundles and generator feeder cables to the No. 2 engine-driven generator. However, all essential electrical services remained operable through the tie bus which interconnects the aircraft's three electrical power sources.

Thus, the Safety Board believes that, while this accident clearly demonstrates the potential for a catastrophic accident as a result of a separation of a major engine component which could cause major structural damage or render multiple redundant systems inoperable, the accident nevertheless demonstrates the value of system redundancy in the design philosophy of modern transport category aircraft.

3. CONCLUSIONS

3.1 Findings

1. The aircraft was properly certificated and had been maintained in accordance with approved procedures.
2. The flightcrew was properly certificated and medically qualified for the flight.
3. There was no evidence of preaccident failure or malfunction of the aircraft systems, flight controls, or structures.
4. Weather was not a factor in this accident.
5. Oil leaks between the abutment faces of the IPC rear stubshaft and the LPLB weir and between the abutment faces of the IPLB inner race front flange and the IPC rear stubshaft resulted in an inadequate lubricating oil supply to the LPLB.
6. The LPLB failed because the inadequate supply of lubricating oil caused an increase in the bearing's operating temperature as a result of increased friction.
7. The increase in the LPLB's operating temperature reduced bearing operating clearance and caused individual balls and the bearing cage to seize.
8. The LPLB failure allowed an axial and radial displacement of the curvic coupling seal members of the IPC rear stubshaft.
9. The displacement of the seal members allowed oil to escape from the LPLB and ignite on the hot seal members, creating a stabilized fire in the fan shaft and fail-safe shaft annulus area.
10. The fan shaft failed in torsional shear because heat had degraded the shaft's material properties.
11. The hot gases from the fan shaft annulus fire were carried through the cooling air passages of the fail-safe shaft, overheated and weakened the fail-safe shaft, and led it to fail in a torsional and tensile mode.
12. Inlet flow disturbances and duct-section ingestion after the fan shaft and fail-safe shaft released caused the engine to surge; the engine surge prevented an overspeed of the LPT rotor assembly.
13. The fan module moved about 12 feet forward in the inlet duct and exited through the sides of the duct.
14. The oil leaks were most likely caused by poor mating of the abutment surfaces.

3.1 Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was thermally induced degradation and consequent failure of the No. 2 engine low pressure location bearing because of inadequate lubrication. Oil leaks between the abutment faces of the intermediate pressure compressor rear stubshaft and the low pressure location bearing oil weir and between the intermediate pressure location bearing inner front flange and the intermediate pressure compressor rear stubshaft reduced the lubricating oil flow to the low pressure location bearing which increased operational temperatures, reduced bearing assembly clearance, and allowed heat to build up in the bearing's balls and cage. The bearing failure allowed lubricating oil to spray forward into the low pressure fan shaft area where it ignited into a steady fire; the fire overheated the fan shaft and the fan fail-safe shaft both of which failed, allowing the fan module to move forward and break through the No. 2 engine duct. This caused extensive damage to the aircraft's structure and flight control systems. The oil leaks were most likely caused by poor mating of the abutment surfaces.

4. Recommendations

The Safety Board believes that this accident graphically illustrates the potential hazards of an uncontained failure in a large turbine engine operating at high power. Further, the Safety Board recognizes that the large fragments and rotating components that are released from large turbine engines cannot always be contained within the engine or the nacelle structure with state-of-the-art materials and technology. The Safety Board realizes that during normal operational circumstances, these types of failures occur infrequently when compared to the total number of engine operational hours. Nevertheless, when such a failure does occur the consequences are potentially catastrophic.

The Safety Board recognizes the continuing efforts by the Federal Aviation Administration, the National Aeronautics and Space Administration, the Department of Defense, and engine and aircraft manufacturers to develop new materials and technology to alleviate or minimize the hazards of uncontained engine failures. The Safety Board urges that all these parties continue their current efforts and expand them to develop new materials and technology to minimize these hazards. The Safety Board also believes that the FAA and the manufacturers should review their design and installation criteria based on service experience gained as a result of uncontained failures to assure that the installation design for critical aircraft components minimize their susceptibility to damage in the event of a massive failure, recognizing that these efforts cannot be expected to apply to the separation of an entire module such as occurred in this accident.

As a result of its investigation of an uncontained engine failure on Air Florida DC-10-30F, N101TV, at Miami International Airport on September 22, 1981, the National Transportation Safety Board recommended that the Federal Aviation Administration:

Expedite the publication of guidance material for acceptable means of compliance with 14 CFR 25.903(d)(1), which includes compliance documentation by failure mode and effect analysis, provides for rotor fragment energy levels and paths based on cases of severe in-service damage, and reflects advances in analytical techniques and concepts which have taken place since certification programs of the early 1970's. (Class II, Priority Action) (A-82-38)

Actively encourage research and development in containment technology and engine reliability, including basic design concepts, manufacturing processes, and maintenance factors to detect and prevent impending failures. (Class II, Priority Action) (A-82-39)

Also, as a result of the Eastern Airlines Flight 935 accident and the previous incidents, the engine manufacturer, the aircraft manufacturer, and L-1011 operators have adopted short-, intermediate-, and long-term corrective actions with respect to engine-build procedures and the installation of new configuration parts. These corrective actions follow:

Short Term--The engine manufacturer revised the engine overhaul manual with respect to procedures to be adopted when building up the IPC rear stubshaft assembly. These procedures recommend restoration of the IPC and LPC rear stubshaft bearing and oil weir location faces whenever the module is worked on. Additionally, the engine manufacturer has developed improved, stronger material for the IPLB inner race retention bolts(1/4 inch). These bolts are torqued to 150 in-lbs as opposed to 100 in-lbs for the replaced bolt and are to be installed any time that the intermediate module is exposed.

Intermediate Term--Larger diameter (5/16 inch) IPLB inner race retention bolts are also being provided with torque values of 290 in-lbs. A twin axial oil jet has been installed to increase the oil supply to the LPLB.

A fan retention device has been installed, featuring two snubber rings designed to engage each other in the event of a fan shaft failure. The retention device functions so that if the shaft fails, the fan's forward movement is limited by the snubber ring. The fan retention device was successfully tested on an engine at full power in early 1982. The FAA has issued a proposed airworthiness directive requiring installation of the fan retention devices on all RB-211 engines in a timely manner.

The engine manufacturer also has indicated that the above modifications are being developed with a target date for parts availability early in 1982. These modifications are being designated as "Packages 1B and 3" by the engine manufacturer.

Long Term--The engine manufacturer is conducting an extensive design and development program to modify the front sealing arrangement to the *[sic]*. The engine manufacturer has indicated that the target for introduction of modified engine parts is toward the end of 1982.

Eastern Airlines--As a result of the May 25, 1981 failure, Eastern and other RB-211 operators modified their intermediate module buildup procedures to require handstoning of the LPLB and IPLB and the LPLB oil weir abutment faces which could potentially be subject to abutment face oil leaks. New LPLB inner race retention bolts are also being installed during each intermediate module buildup. Specific new inspection procedures were instituted for fan shafts that were involved in LPLB failures. Eastern has also begun oil sampling of removed L-1011 engines that were performance monitored or evaluated in Eastern's engine test cells.

In August 1981, Eastern began a fleet campaign to check engine oil samples on all of its L-1011 aircraft that remained overnight at its facilities in Miami. It also introduced grinding and lapping to replace the previously required handstoning of the location bearing abutment faces. All suspect fan shafts involved in serious LPLB failures were removed and were returned to the engine manufacturer.

As a result of this accident, Eastern retained a bearing expert to investigate the LPLB problem; the bearing consultant spent 8 days investigating the LPLB bearing problem at the engine and bearing manufacturer's facilities and is currently evaluating the LPLB design through a National Aeronautics and Space Administration bearing evaluation program. Eastern has also begun installation of the LPLB bearing inner race retention bolts made of stronger material, and torquing these bolts to the engine manufacturer's prescribed limits. Eastern has also begun a controlled 30-day program of engine oil analyses and magnetic chip detector inspections of engines installed on L-1011 aircraft which remain overnight in Miami, Atlanta, John F. Kennedy International Airport, Newark, Boston, and Los Angeles. As new and replacement engine components become available, Eastern intends to incorporate the intermediate- and long-term component replacements as specified by the engine manufacturer.

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June 1, 1982

5. Appendixes

Appendix A Investigation And Hearing

1. Investigation

The Safety Board was notified of this accident about 1230 on September 22, 1981. A partial team of investigators was dispatched immediately from *[sic]*. Safety Board's Headquarters in Washington, D.C., and arrived in New York about 1600. Working groups were established for systems/structures, *[sic]* powerplants, maintenance records, metallurgy, flight data recorder, and cockpit *[sic]*.

Parties to the investigation were the Federal Aviation Administration, Eastern Airlines, Rolls-Royce, Ltd., Lockheed Aircraft Company, Airline Pilots Association, and the International Association of Machinists.

2. Hearing

A public hearing was not held, and depositions were not taken.

Appendix B Personnel Information

Captain

Captain Adam C. Kagel, age 58, holds Airline Transport Pilot Certificate (ATP) No. 439446 with ratings for airplane single/multiengine land. His first-class medical certificate was issued on April 16, 1981. Captain Kagel had about 21,600 total flying hours with 1,649 hours in the L-1011 at the time of the accident.

First Officer

First Officer Richard B. Donica, age 40, holds Airline Transport Pilot Certificate (ATP) No. 155 9112 with ratings for airplane single/multiengine land. His first-class medical certificate was issued on March 2, 1981. First Officer Donica had about 9,095 total flying hours with 861 hours in the L-1011 at the time of the accident.

Second Officer

Second Officer John L. Barrett, Jr., age 49, holds Flight Engineer Certificate (FE) No. 1926279 with a turbojet rating. His first-class medical certificate was issued on February 27, 1981. Second Officer Barrett had about 11,239 total flying hours with 4,695 hours in the L-1011 at the time of the accident.

Appendix C Aircraft Information

Lockheed L-1011-385-1, N309EA, manufacturer's serial No. 193A-1610, was delivered to Eastern Airlines by the Lockheed California Company on July 25, 1972, and has been operated continuously by Eastern since. The aircraft's total time on September 22, 1981, was 23,902.44 hours, with 12,149 total aircraft cycles.

The aircraft was equipped with three Rolls-Royce Model RB-211-22B engines.

Engine	No. 1	No. 2	No. 3
Serial Number	10131	10101	10103
Time Since Installation	3778 hrs.	87 hrs.	118 hrs.
Time Since Restoration	3778 hrs.	87 hrs.	118 hrs.
Total Time	19,165 hrs.	17,980 hrs.	18,356 hrs.
Total Cycles	9,876	9,367	9,389
Date Installed	5/14/80	9/11/81	9/4/81
Cycles Since Restoration	1,868	46	67

The records review indicated that the aircraft had received the following inspections:

Last "A" Check Segment	9/16/81
Last "C" Check Segment	6/10/81
Last "D" Check	4/7/79

Eastern Airlines L-1011 continuous airworthiness program entails the following:

The "A" checks are accomplished every 260 flight-hours and are scheduled in two segments at 130-hour intervals. A 15-hour window is approved for possible scheduling problems.

The "C" checks are 405-day periodic service inspections scheduled in three segments of 135 days each.

The "D" checks are primarily structural evaluations and restorations of the aircraft and are scheduled at 8-year intervals for first cycle aircraft, at 6-year interval for second cycle aircraft, and at 5-year intervals for third and subsequent cycle aircraft.

A review of the Airworthiness Directives (AD's) was accomplished, and the records indicated that all applicable AD's were recorded and complied with. Service Difficulty Reports submitted to the FAA since the No. 2 engine was installed on September 11, 1981, were reviewed and did not reveal any significant problems.

No. 2 Engine History

The engine, S/N10101, was installed on the accident aircraft on September 11, 1981, following restoration and testing at the facilities of Eastern Airlines in Miami, Florida. The restoration was generated by a cracked high pressure turbine blande.

On September 13, 1981, the following discrepancy was entered into the log book:

During rotation momentarily loss of power on No. 2 engine. All parameters low, about 1.2 EPR. Power came back after lift off with all parameters back to normal. Check N₂ power overspeed pointer. On a go around in MIA power and parameters normal.

Corrective action taken:

N2 overspeed sensor checked and found to be normal. Note: Engine O.K. on go around in Miami and request outbound crew to give more detailed information if any problems encountered. Please give enroute parameters on top section of log book.

Outbound flightcrew entered the following note:

As per request page 35 this log No. 2 engine appears normal.

The times/cycles on No. 2 engine 03 Module/LPLB at the time of the accident were:

Total Time 03 Module S/N AM553	11,462 hrs.
Total Time Since 03 Module Restoration	2,900 hrs
Total Time Low Pressure Location Bearing S/N P102	11,841 hrs.
Time Since Restoration Low Pressure Location Bearing	2,900 hrs.

The low pressure locating bearing restoration was accomplished in accordance with an EAL engineering order. Review of the engine records indicated that all required AD's had been complied with and that the engine had been maintained in accordance with EAL approved maintenance program. All life-limited and time-controlled components are computer controlled and were shown to have been within the required time limits, including inspections and checks.

¹All times are eastern daylight saving, based on the 24-hour clock.

²All altitudes are mean sea level.

⁵When the engine is operating at high power conditions, the vector forces associated with compressor rotation are directed forward. However, the rearward directed vector forces associated with the rotational driving forces of the compressor's mating turbine are greater than the compressor driving forces; therefore, the predominant loads experienced by the location bearings are directed rearward. When the engine is operating at a low power condition, the converse is true, thus loading the location bearings in a forward direction. The engine manufacturer estimated that these loads are about 4,000 lbs maximum, in a rearward direction, at sea level takeoff thrust conditions, and about 1,500 to 2,000 lbs maximum in a forward direction, during low power operating conditions.